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Decline and mortality of Black Spruce caused by Spruce Budworm defoliation and secondary organisms

A.G. Raske and W.J. Sutton

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DECLINE AND MORTALITY OF BLACK SPRUCE CAUSED BY SPRUCE BUDWORM DEFOLIATION AND SECONDARY ORGANISMS

by A.G. Raske and W.J. Sutton

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ABSTRACT

During the recent outbreak of the spruce budworm (*Choristoneura fumiferana* (Clem.)) in Newfoundland, black spruce stands (*Picea mariana* (Mill.) B.S.P.) were also severely defoliated for three to four years between 1976 and 1979. Tree mortality was about 500 000 m^3 by 1981 but increased sharply to 2 002 000 m^3 in 1982 and to 3 194 000 m^3 in 1983. The total stand volume containing these dead trees was 10 322 000 m^3 and this volume occurred in an area of 95 700 ha. In addition dead trees comprising less than 10% of the stand volume were recorded on about 100 000 ha. Some degree of topkill occurred on nearly 100% of surviving spruce.

Symptoms of decline and mortality were reddening and dropping off inner foliage in the fall, followed by increasing crown mortality and then death.

The bark beetle *Polygraphus rufipennis* (Kirby) successfully attacked trees with all degrees of foliage remaining on the trees. In general, surviving trees in stands classed as severely damaged had a greater probability of being attacked than trees in stands with less damage. The root rot *Armillaria* sp. (*mellea* complex) was also active in stands of various degrees of crown damage, but was prominent in trees with 80% or more cumulative total defoliation. Both organisms enhanced the rate of tree mortality and probably also its extent.

Rootlet mortality had occurred during the past years of severe defoliation. Rootlet recovery two to three years after cessation of defoliation lagged behind foliage recovery in trees sampled. This may have led to water stress and favored the establishment of normally secondary organisms.

The balance between crown recovery and rootlet recovery combined with bark beetle activity and root rot attack affected the decline and mortality of a large number of severely damaged black spruce. Both decline and mortality abated in 1984 and more so in 1985. Trees that survived to 1985 are likely to recover completely.

RÉSUMÉ

Au cours de la récente infestation de la tordeuse des bourgeons de l'épinette (Choristoneura fumiferana (Clem.)) à Terre-Neuve, les peuplements d'épinette noire (Picea mariana (Mill.) B.S.P.)) ont été aussi gravement attaqués pendant 3 ou 4 ans, de 1976 à 1979. la mortalité des arbres a été d'environ 500 000 m^3 en 1981 et a grimpé abruptement pour atteindre 2 002 000 m^3 en 1982 et 3 194 000 m^3 en 1983. Le volume total des peuplements contenant es arbres morts était de 10 322 000 m^3, dans une région de 95 700 ha. En outre, des arbres morts comptant pour moins de 10% du volume des peuplements ont été enregistrés sur environ 100 000 ha. La totalité des épinettes qui ont survécu sont ateintes, à des degrés divers, par la cime.

Les symptômes du déclin et de la mortalité étaient le rougissement et la chute du feuillage intérieur à l'automne, suivis par une mortalité accrue de la cime et ensuite, la mort.

Le polygraphe de l'épinette (Polygraphus rufipennis (Kirby)) a attaqué avec succès les survivants, quelle que soit la proportion de feuillage restant. En règle générale, les arbres survivants dans les peuplements considérés comme gravement ravagés avaient plus de chances d'être attaqués que ceux des peuplements moins endommagés. Le pourridié-agaric Armillaria complexe mellea a également fait des ravages dans les peuplements où les cimes étaient endommagées à des degrés divers, mais ses ravages étaient les plus évidents sur les arbres ayant subi une défoliation totale cumulative de 80% ou plus. Les deux ravageurs ont fait augmenter le taux de mortalité des arbres et probablement aussi son étendue.

Il y avait en mortalité des radicelles pendant les dernières années de défoliation grave. Le rétablissement des radicelles, de deux à trois ans après l'arrêt de la défoliation, a retardé la rétablissement du feuillage chez les arbres étudiés. Cela peut avoir abouti à un manque d'eau et favorisé la prédominance d'organismes habituellement secondaires.

L'équilibre entre le rétablissement de la cime et celui des radicelles, combiné à l'activité ou polygraphe de l'épinette et aux attaques du pourridié-agaric, a entraîné le déclin et la mort d'un grand nombre d'épinettes noires gravement endommagées. Le déclin et la mortalité ont commencé à diminuer en 1984 et le processus s'est accentué en 1985. Les arbres qui ont survécu jusquen 1985 se rétabliront probablement complètement.

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DECLINE AND MORTALITY OF BLACK SPRUCE CAUSED BY SPRUCE BUDWORM DEFOLIATION AND SECONDARY ORGANISMS

by

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INTRODUCTION

The forested lands of Newfoundland are composed mainly of balsam fir (*Abies balsamea* (L.) Mill.) and black spruce (*Picea mariana* (Mill.) B.S.P.), with black spruce comprising about 34% of the total volume (Page *et al.* 1974). Black spruce has been thought to be fairly resistant to damage by most insects including the spruce budworm (*Choristoneura fumiferana* (Clem.)). An outbreak of the spruce budworm started in Newfoundland in the early 1970s and lasted till 1981 in most areas affected. By 1981 mortality of black spruce was only 5% of the total tree mortality and this occurred mainly among severely damaged fir stands, but some mortality also occurred in several spruce stands between Badger and Springdale (Raske *et al.* 1986). Observations of spruce stands in central and eastern Newfoundland showed good recovery of black spruce; evidenced by abundant and good shoot growth and new leader formation where tops had been killed. Recovery in some stands was not as good in 1981 as in most stands, but this was not alarming. However, by the fall of 1982 mortality of black spruce had increased considerably.

This report outlines the defoliation history of black spruce during the recent spruce budworm outbreak, presents estimates of spruce

mortality from 1977 to 1983, gives symptoms of dying spruce, describes mortality rates of spruce, and forecasts damage.

DEFOLIATION HISTORY OF BLACK SPRUCE

The area and severity of annual defoliation by the spruce budworm for Newfoundland, including Labrador, has been published by the Newfoundland Forestry Centre in the local and national Forest Insect and Disease Survey annual publications, and in special annual reports on the status of the budworm outbreak, beginning in 1977. A special summary was done in what is now called "The Commission Report" (Hudak and Raske, ed. 1981). However, in all these publicaticns defoliation of black spruce by the spruce budworm is not distinguished from that of balsam fir and may have been as severe, or less severe, than that reported for fir in the same area. Nevertheless defoliation categories published for those areas in which black spruce is dominant can be assumed to be for spruce. Thus, information from these defoliation maps combined with sampling records, data from temporary and permanent plots, plus observation by field personnel provide a reasonable defoliation history for much of the spruce regions of Newfoundland. Defoliation of black spruce was always confined to the current foliage. No feeding on older shoots has been observed on a stand basis.

Black spruce is not common on productive forest lands in the western region of the Island, but whatever spruce existed was severely defoliated in 1976 and some may also have been defoliated in 1975 or in 1977 - but probably not in both years.

In central Newfoundland black spruce forms extensive even-age stands that originated after fire. Stands between Badger and Springdale were severely defoliated in 1975. These and most other stands were then annually defoliated from 1976 to 1979 inclusive. In 1978 and 1979 the spruce coneworm (Dioryetria reniculelloides Mutuura and Munro) contributed to the total defoliation recorded; up to 60% locally. However, the type of damage to the host by the coneworm is similar to that caused by the budworm. In 1980 defoliation of spruce was generally not as severe as that on the adjacent fir and most of it was caused by the coneworm. Branch samples collected in 1983 from surviving trees showed branch-terminal growth began in 1979 in some areas and was well underway by 1980 in most spruce areas. Only a very small amount of mortality, scattered within the stands, had occurred by 1981. Recovery seemed quite advanced by July of 1982, such that surviving trees in most stands appeared near normal.

In eastern Newfoundland the defoliation history of spruce was very similar to that in the central area except that it was delayed by one year; beginning in 1977 and ending in 1980. Recovery growth began in 1980, and was well underway by 1981.

It is not known why large areas of spruce were annually defoliated for three to five years, since black spruce areas do not normally sustain outbreak populations of the budworm. The influx of large moth flights from the fir forests of the western region could have been mainly responsible for maintaining high population levels of the budworm in central and eastern Newfoundland spruce forests.

METHODS OF SAMPLING DAMAGE AND MORTALITY

Methods of estimating amounts of tree mortality varied during the outbreak; increasing in detail and improving in precision as the outbreak progressed, and as the need increased for more accurate tree mortality estimates. The various methods have been published (Otvos and Moody 1978; Moody 1979; Moody and Otvos 1979; Moody 1980; Raske and Clarke 1982; and Raske et al. 1982, 1986), and only a few pertinent points will be presented here. Damage assessment plots, consisting of prism sweeps, were established in 1977 and the number of sampling points increased each year; 20 plots in 1977, 221 in 1978 and 376, 340, 487, 975 and 637 in 1979 to 1983 respectively. To maximize the data for black spruce all plots were included if they contained at least one spruce tree. Many plots were in western Newfoundland, where spruce is not common in productive forests, therefore the average number of spruce trees per plot was low. Each tree in the assessment plot was classified as living or dead, the number of years-since-death for dead trees, and for living trees the percent of defoliation was estimated by 20% classes (Sutton 1981). Classes were assigned numerical codes corresponding to the mid points of the units: codes 1, 3, 5, 7, 9 correspond to total defoliation averages of 10%, 30%, 50%, 70% and 90% respectively.

Permanent plots were established in 1975 to monitor the impact of the spruce budworm. A few plots were added in later years as the area of infestation expanded. A few plots were also lost due to logging. A maximum of 16 plots in black spruce stands were available for recording budworm defoliation and tree mortality.

In the fall of 1982 when the rapid decline of black spruce began, 58 special prism-sweep plots were examined in damaged spruce stands to establish the frequency of occurrence of the four-eyed spruce bark beetle, Polygraphus rufipennis (Kirby), in dead and living trees. Total defoliation and presence or absence of bark beetles was recorded for each tree.

In 1982, 12 plots each measuring 20 m by 50 m were established to monitor tree mortality in mature spruce stands. Two plots were chosen in each of a light damage class, moderate class and in the severe damage class in the South Brook River watershed (Halls Bay), and a replicate of this design established in the Northwest Gander River watershed. Four additional plots were established in young stands to record progress of mortality in this age class. Annual records taken in August and the fall on the plots included degree of total and current defoliation, crown class, tree diameter, height and living or dead, and presence of the four-eyed spruce bark beetle.

The root systems of 192 black spruce trees were exposed by washing away the soil with pressurized water. The root systems were then examined for Armillaria sp. (mellea complex) within a week after being washed, and the number and size of Armillaria infections in the roots and root collar were mapped and recorded for each tree. The number of Hylobius warreni Wood, larval gallaries was also recorded.

In late August part of the root system of eight damaged trees near Grand Falls were carefully exposed, using a high volume of water

under very low pressure, to maximize the retention of fine roots and root hairs. One living but damaged tree sampled had good recovery growth and after felling the tree it was judged to have 40% crown mortality. It appeared to be one of the healthiest trees in the stand. However it had been successfully attacked by P. rufipennis, and no gallery was found that was older than one week. For each tree at least three complete roots were exposed. An undamaged spruce to serve as a control, could not be found in central Newfoundland, therefore a tree was selected on the Avalon Peninsula in the Salmonier River Valley in a stand known to have been without budworm defoliation.

DAMAGE TO BLACK SPRUCE

Defoliation

In spruce budworm damaged areas by 1978 about 90% of the spruce trees had less than 40% of their total foliage removed; i.e. had defoliation codes of 1 or 3 (Table 1). The remaining 10% were about equally divided among the three higher defoliation categories. These proportions changed very little until 1982; except for the small but steady increase in the number of dead spruce trees. By examining the table it is apparent that not all of the increase in dead spruce could derive from the most severely defoliated trees, but that some lightly to moderately defoliated trees had died as well. This was substantiated by our observations. The quantity of foliage on spruce is not a good indicator of the probability of the death of the tree. By 1982 only about 56% of the

Table 1. Percent of black spruce stems by total defoliation classes in stands defoliated by the spruce budworm in Newfoundland from 1977 to 1983 (see text for explanation).

Year	No. black spruce trees	Total Defoliation Code					Dead
		1	3	5	7	9	
1977	39	79	10	0	0	3	8
1978	476	76	10	4	2	1	6
1979	1 095	75	11	3	1	1	9
1980	1 064	73	9	3	1	2	12
1981	1 408	58	15	6	2	2	17
1982	2 732	29	27	12	6	4	22
1983	5 283	38	29	10	3	1	19

spruce were in the two low defoliation categories and 22% had died. The increase in mortality in 1983, experienced in many areas is not reflected by the data in this table because many of the new plots had been placed in lightly-damaged areas.

The average total defoliation of the 16 permanent plots increased slowly from 1977 to 1981 approaching an average of nearly 45% (Table 2). This was thought to be not critical for spruce survival. It would have been higher in 1980 and 1981 but for the new growth put on by many trees. A season of good shoot growth in 1982 reduced the average total defoliation to about 30%. By this time the most severely defoliated branches in a tree had died and total defoliation estimates is best considered percent crown mortality.

Table 2. Average current and total defoliation of black spruce in Newfoundland on temporary prism and on permanent plots in areas damaged by the spruce budworm in Newfoundland from 1975 to 1984.

	Temporary Plots			Permanent Plots		
		Average defoliaton (%)			Average defoliation (%)	
Year	No. plots	Current	Total	No. plots	Current	Total
1975	0	-	-	12	29	-
1976	0	-	-	14	86	-
1977	20	85	15	14	91	(24)
1978	221	23	15	16	54	34
1979	376	40	15	16	72	35
1980	340	48	17	14	57	40
1981	487	14	20	14	4	44
1982	975	14	32*	14	1	29*
1983	637	1	25*	14	0	20*
1984	-	-	-	14	0	21*

*This now considered percent crown mortality.

Both current and total defoliation in the temporary plots are consistently lower than those in the permanent plots (Table 2). Temporary plots were located predominantly in western Newfoundland because much fir was damaged there, but where black spruce was not severely defoliated. When the data from the western plots were excluded the defoliation estimates of the two plot types are comparable.

Mortality

Mortality of black spruce began in 1977 and was estimated at 8 000 m^3 (Table 3). Mortality increased annually reaching 507 000 m^3 by 1981. The dead volume from 1977 to 1979 to a large extent was scattered

Table 3. Cumulative areas and volumes of dead and severely damaged black spruce, in areas of more than 10% tree mortality in Newfoundland from 1977 to 1983.

Year	Area (ha)	Volume (m^3)		
		Severely damaged	Dead	Total stand
1977	12 000	600	18 000	-
1978	19 000	7 000	57 000	-
1979	49 000	26 000	216 000	-
1980	66 000	150 000	420 000	-
1981	67 000	78 000	507 000	-
1982	81 000	464 000	2 002 000	8 233 000
1983	95 700	915 000	3 194 000	10 322 000

trees and patches of dead spruce within areas of high balsam fir mortality. However in 1980 and 1981 spruce stands in the South Brook (Halls Bay) river drainage contained sizable volumes of dead trees. Also a small area of concentration of dead spruce occurred in the spruce stands in the Northwest Gander River drainage near the Bay d'Espoir Highway.

Severely damaged spruce trees, with total defoliation codes of 7 and 9, comprised only 600 m^3 in 1977, increased to 150 000 m^3 by 1980 and then decreased sharply to 78 000 m^3 in 1981 (Table 3). This decrease was thought to be evidence of recovery. A drastic reversal took place in 1982 and the volume of spruce in this category jumped to 464 000 m^3 and to 915 000 m^3 in 1983. These data best reflect the general spruce decline that had occurred.

Tree mortality also increased greatly in 1982 and 1983. The large increase to 2 002 000 m^3 in 1982 occurred mostly in the fall and mostly in central Newfoundland. Spruce continued to die in the winter and spring of 1982-83. By 1983 another 1 000 000 m^3 of spruce had died for a total of 3 194 000 m^3. Much of the 1983 increase occurred in eastern Newfoundland, and the remainder in central Newfoundland.

Comparable figures for 1984 and 1985 have been collected by the Newfoundland Department of Forest Resources and Lands but have not yet been released. However, our observations indicate a virtual cessation of decline and mortality of spruce. Trees that survived to 1985 seemed to have fully recovered and are unlikely to die in the near future.

The areas and volumes of spruce mortality recorded in Table 3 consists only of stands with more than 10% of the stand volume dead. In addition, dead trees comprising less than 10% of the stand volume were recorded on about 100 000 ha in 1983 (Fig. 1). Assuming an average stand volume of 100 m^3/ha and 5% mortality, then the dead volume in these stands is estimated at 500 000 m^3 and the total stand volume at 10 000 000 m^3.

Areas of black spruce mortality were scattered in central and eastern Newfoundland with most of the larger areas in central Newfoundland (Fig. 1). Mortality occurred mostly in the headwaters of rivers that empty into Notre Dame Bay, the headwaters of the Gander River and those of Triton Brook. Some mortality had occurred in most areas of concentrations of mature spruce (100 + years old), though some mortality

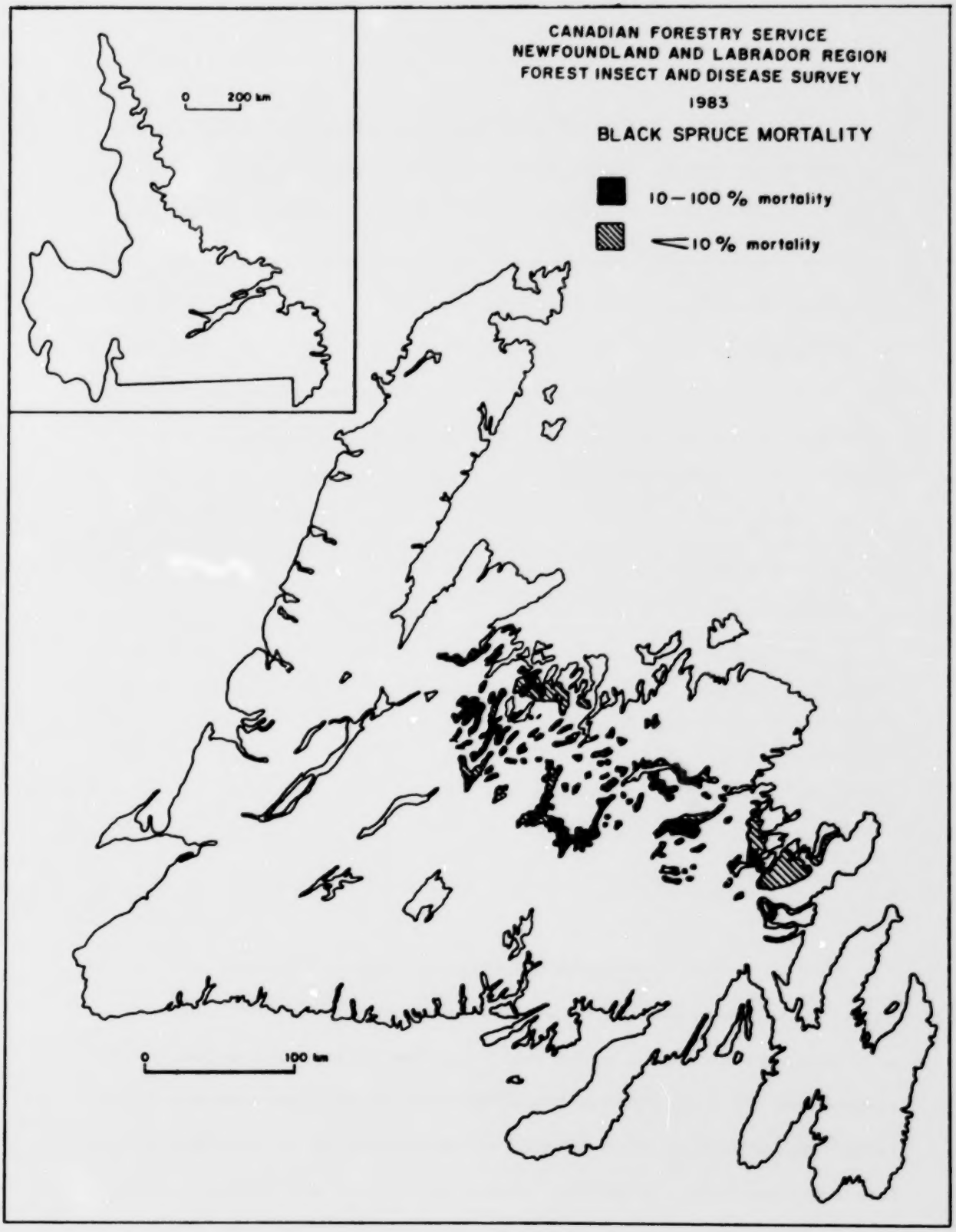

Figure 1. Areas of black spruce mortality following spruce budworm damage and attack by other pests in Newfoundland in 1983.

had also occurred in relatively young stands near Great Rattling Brook (40 years old) and near Grand Falls (50 years old).

Topkill

Some degree of topkill of black spruce caused by spruce budworm feeding occurred on nearly all surviving spruce by 1981 (Table 4). About 30% had dead tops longer than .2 m. Many tops had new leaders by 1982 which will results in crooks in the stem or in multiple leaders. However, smaller topkill may be completely overgrown especially in younger trees.

Table 4. Percent of black spruce tops damaged by spruce budworm feeding in Newfoundland from 1979 to 1983.

Year	Total no. spruce trees	% Black Spruce Tops				
		Undamaged	Dead < .2 m	Dead .2-1 m	Dead 1-3 m	Dead > 3+m
1979	1 032	37	15	25	9	14
1980	940	25	36	32	3	4
1981	1 172	1	62	30	4	3
1982	4 992	0	73	19	6	2
1983	5 283	0	73	21	5	1

SYMPTOMS OF DECLINING VIGOR

Spruce stands with increased tree mortality in 1982 shared several conspicuous symptoms of declining vigor. The most obvious symptom was the discoloration and sudden loss of the inner foliage in the fall. Spruce needles are generally retained for five to six years. In late September 1982 the needles, except for the two most current years,

turned yellow and then bright red-brown and dropped by mid-October, leaving a shell of green foliage. This reduced needle content on the trees, allowed the black lichens (Alectoria sarmentosa (Ach.)), abundant in the inner crowns of mature black spruce, to be visible, giving black spruce trees and stands a black hue. Another symptom was the abundance of tree-top mortality throughout the stands, and lastly, portions of the crown died as branches or clusters of branches died.

The turning and dropping of old foliage may have been a phenomenon similar to that recorded in British Columbia for Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) (Ross et al. 1978). When trees were defoliated by the western spruce budworm (C. occidentalis Freeman), older needles were retained by the tree, apparently retaining their function longer than normal. After defoliation had ceased for a year or two and a sufficient crop of new needles had regrown, the old needles retained abnormally long, were dropped. Since black spruce in Newfoundland had a similar defoliation history as that of Douglas fir, the reaction of the trees may have been the same. However, the top and crown mortality in black spruce indicated more severe damage to the tree than that received by the Douglas fir.

It was also observed that some needles died without turning color. Striking a tree with a hard blow would cause a rain of green needles that were obviously drier than normal.

Shoot growth of both surviving trees and trees that died in fall of 1982 was better than in years previous both in 1981 and in 1982 (Fig. 2).

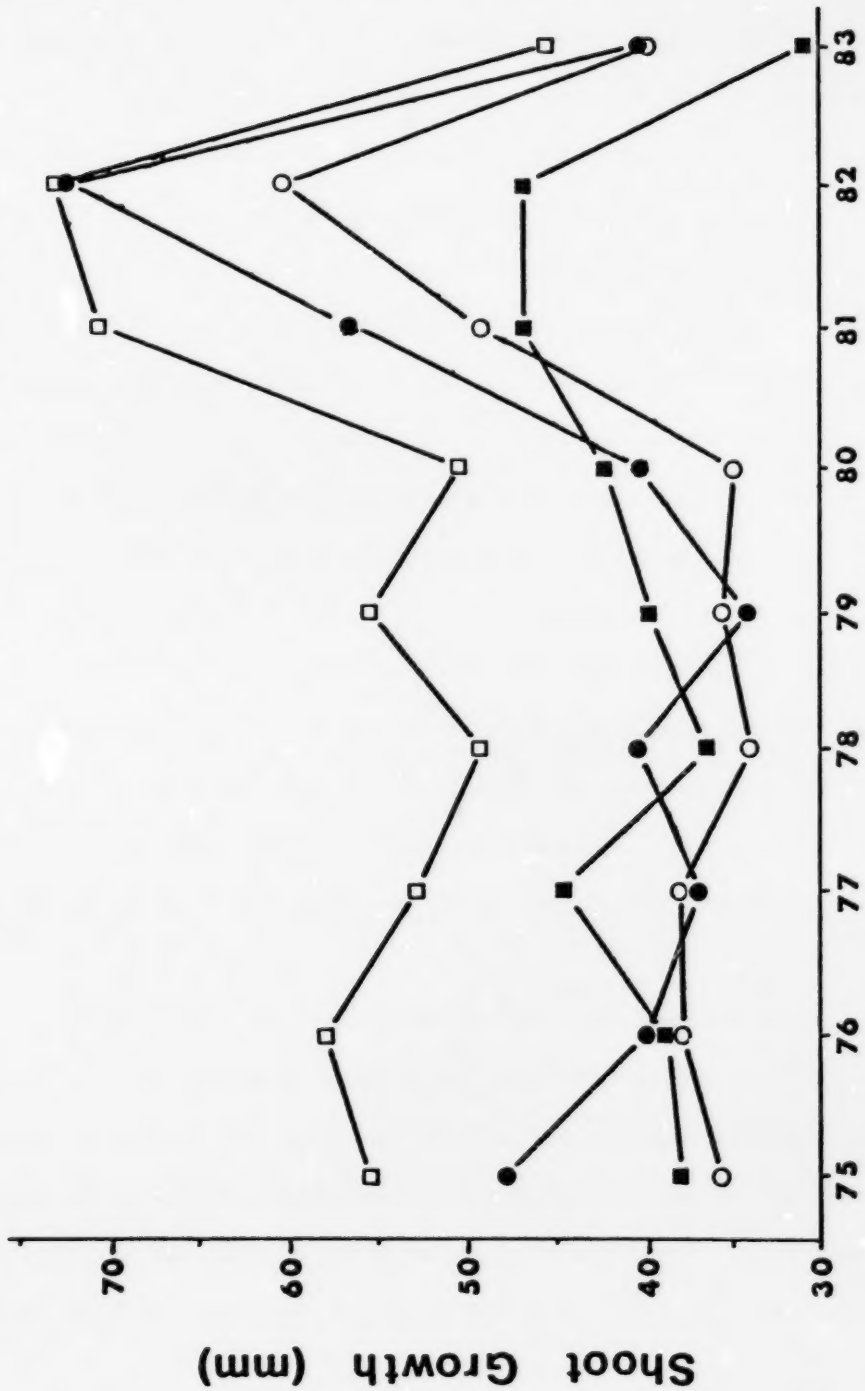

Figure 2. Average annual terminal shoot growth in mm of mid-crown branches in black spruce plots in Newfoundland. O = Light damage, ● = Moderate damage, ■ = Severe damage, □ = Young stands.

Average terminal shoot length of midcrown branches of surviving trees ranged between 35 mm and 42 mm from 1975-80, but then reached about 50 mm in 1981 and 60 mm in 1982. Terminal shoot growth did not indicate a decline in tree vigor.

Several trees were cut and the annual increments at breast height measured. No obvious reduction of radial increment caused by spruce budworm defoliation in 1976 to 1979 was noted (Fig. 3), because the trees were mature and their increment at a low level before the budworm outbreak. The growth pattern illustrated (Fig. 3) was typical of the trees sampled.

SECONDARY FACTORS OF SPRUCE MORTALITY

All black spruce stands with tree mortality had been severely defoliated by the spruce budworm for several years, causing some mortality directly and widespread topkill. We concluded that this defoliation pressure predisposed the trees to secondary factors that influenced whether damaged trees recovered or succumbed. The role of these factors is considered slow.

Four-eyed Spruce Bark Beetle

The four-eyed spruce bark beetle, Polygraphus rufipennis (Kirby), can establish itself in several conifers, but it is most abundant in species of spruce, including black spruce. In this tree species the beetle is considered an aggressive secondary insect being only occasionally found in trees with green foliage (Hilton 1968). When this has occurred the death of the tree was attributed to the bark beetle.

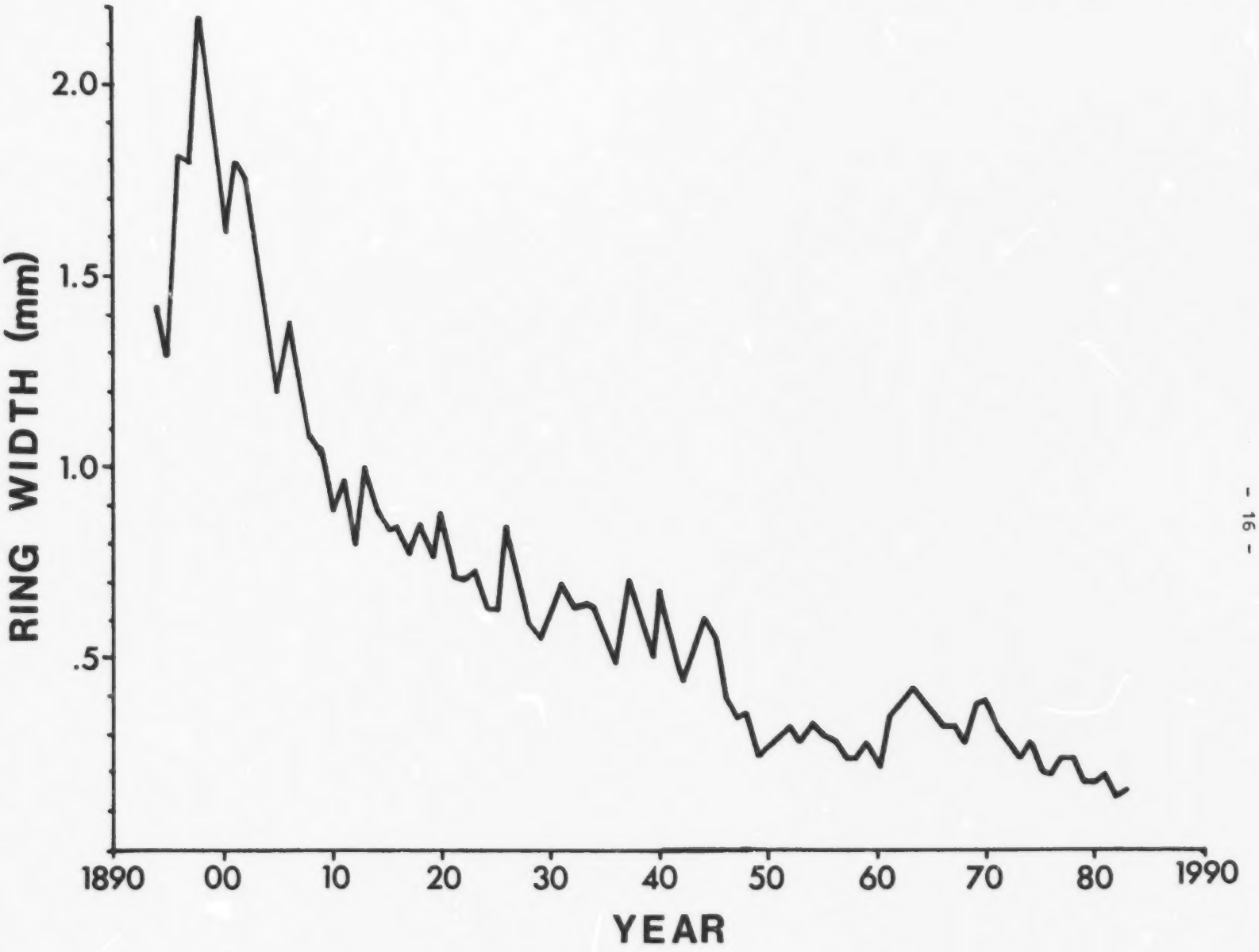

Figure 3. Typical increment at breast height of budworm-damaged mature black spruce trees in Newfoundland.

Data from the 58 prism-sweep plots to determine the abundance of P. rufipennis, showed that 54 plots contained some spruce mortality and the bark beetle was present in 46 plots. About 90% of the dead trees were currently or had been infested with the bark beetle, and successful attacks occurred in all but defoliation category 3 (Table 5). The percent of trees successfully attacked by the beetle increased with the severity of total defoliation category.

Table 5. Number and percent of black spruce trees dead in 1983, with the four-eyed spruce bark beetle, Polygraphus rufipennis, by 1982 total defoliation categories.

	No. dead in 1982 or before	Living in fall of 1982 but dead in 1983				
		Total defoliation class in 1982				
		9	7	5	3	1
No. trees in category	293	52	53	112	155	198
No. trees with Polygraphus	267*	12	5	7	0	4
% of trees with Polygraphus	91	23	9	6	0	2

*Current and old attacks.

The beetle was active in all 16 spruce-mortality plots in 1982 (Table 6). All plots examined in the fall of 1982 had trees with overwintering brood of P. rufipennis, and most of these trees retained some yellow or brown needles indicating they had had green needles when attacked. Based on bark examination, most of the 72% of the dead trees had died in 1981 and 1982, though a few may have been dead up to six years.

Table 6. Number of black spruce trees and percent mortality with and without the four-eyed spruce bark beetle, Polygraphus rufipennis, in Newfoundland from 1982 to 1985.

Damage class of stand	Total no. trees in plots in 1983	% Living in 1983	% Dead 1982 and before		1983		1984			1985		
					% Dead		No. living trees in spring	% Dead		No. living trees in spring	% Dead	
			with Polygraphus	without Polygraphus	with Polygraphus	without Polygraphus		with Polygraphus	without Polygraphus		with Polygraphus	without Polygraphus
Mature												
Light	665	91	5	1	3	0	605	3	0	587	1.4	0
Moderate	665	70	10	7	13	0	466	5	0	442	5.6	0
Severe	1 011	12	72	6	10	0	127	6	0	119	3.4	0
Young	2 157	80			5	0	1 726	2	0	1 691	1.2	0

Newly attacked trees also occurred on all plots in 1983 (Table 6). Almost all attacks in early June occurred on trees with green foliage on them. The largest number and percent of trees dying were in plots classed moderate in total damage. Trees continued to die in 1984 and 1985 but generally at a decreased rate each year. All trees that died in those two years also had bark beetle brood in them. Younger trees generally had lower percent mortality than the mature trees (Table 6).

In each year from 1983-85 the bark beetle successfully invaded trees of all cumulative total defoliation classes (Table 7). In 1983 nearly half of the 204 trees attacked and subsequently died had been classed as 100% defoliated (but alive) in October 1982. Another 70 trees had 80% or more of the foliage removed. The remainder of the defoliation classes were about equally attacked except for larger number of trees in the 40% and 50% defoliation classes. In general, trees in stands classed severely damaged had greater proportion of trees being attacked. This could be caused by either higher beetle populations in these stands, or by the increased susceptibility of trees in stands having had received more budworm damage in the late 1970s.

In 1984 and 1985 beetle attacks were more evenly distributed among the defoliation classes than in 1983, even though trees in defoliation classes of 70% to 90% were slightly more frequently attacked (Table 7). As expected younger trees were less frequently attacked. The tendency for trees of all defoliation classes to succumb to attack is

Table 7. Number of black spruce trees attacked by the four-eyed spruce bark beetle, Polygraphus rufipennis, from 1983 to 1985 and total defoliation class one year previous to tree death.

Tree age and year of death	Total Defoliation Class of the Previous Year										Total no. trees
	10	20	30	40	50	60	70	80	90	100	
Mature 1983	5	5	5	9	10	5	6	23	47	89	204
1984	0	3	2	3	8	3	9	11	8	0	47
1985	0	4	6	3	5	3	5	3	8	0	37
Immature 1984	1	3	4	3	2	0	3	5	6	11	38
1985	1	2	1	1	2	1	5	0	2	5	20

evidence that for black spruce the amount of foliage present is poorly correlated with the probability of survival.

Armillaria Root Rot

The root rot Armillaria sp. was present in the root systems of trees with all degrees of cumulative total defoliation. At least some trees in each defoliation class had a sizable dead root or roots with Armillaria mycelial fans on the cambial surface. However, the frequency and severity of Armillaria root infection varied with defoliation class (Table 8).

The proportion of trees with at least some area of roots with successful Armillaria infection was below 30% for all defoliation categories below 80%, but increased sharply to 85% of the trees infected when total defoliation was more than 80% (Table 8).

The proportion of root surface infected showed a similar trend. Percent infection increased slightly from 1% to 10% in total defoliation categories up to 80%, but with defoliation above 80%, percent infection increased to 75%.

Table 8. Amount of Armillaria sp. (mellia complex) present in root systems of spruce budworm damaged black spruce in Newfoundland in 1983.

Cumulative crown mortality	No. trees sampled	% Trees with Armillaria	Total root surface examined (cm^2)	% Root surface with Armillaria	Total root collar surface examined (cm^2)	% Root collar surface with Armillaria
0-20	58	8.6	3756	0.7	539	0.0
21-40	36	19.4	2935	6.9	475	13.1
41-60	37	29.7	4132	6.1	572	3.5
61-80	28	25.0	3234	10.5	434	2.4
81-100	33	84.8	2084	75.5	267	63.9

The proportion of root collar surface infected was more erratic but also had a similar trend. Percent of surface infected remained below 13% in defoliation classes below 80% and rose sharply to 64% in trees with more than 80% defoliation (Table 8).

The root collar of a number of living trees selected at random, were checked in 1982 and 1983 for Armillaria mycelial fans. Five trees were found with Armillaria mycelial fans completely girdling the root collar. Though these trees had good recovery growth and exhibited no symptoms of disease, their death within a year was virtually certain. Therefore, on rare occasions trees that seem to be in good health, have their vigor reduced to a level, at least temporarily, to enable Armillaria to spread rapidly through the root system into the root collar. No bark beetles were present in these five trees at the time of examination.

The root rot was present in all damaged stands and was able to establish itself in the root system of a sizable number of trees regardless of severity of defoliation pressure. However, it seems that once a tree is weakened beyond a critical point Armillaria appears to grow quickly and invade a large proportion of the root systems. It apparently does not by itself bring weakened trees to the critical point, but the fungus may contribute to the weakening of trees.

Root Collar Weevil

The root collar weevil, Hylobius warreni, was common in the root collars of black spruce whose roots had been exposed to collect Armillaria data. The larvae of this insect mine the inner phloem and cambial region at or near the root collar. When larvae are abundant their feeding weakens the tree.

Hylobius larval tunnels occurred in trees of all damage classes (Table 9). The incidence of Hylobius weevil damage had a tendency to increase slightly with increases in defoliation damage up to 80% defoliation. However observations on the severity of weevil damage indicated that this weevil did not contribute significantly to black spruce mortality, nor to the general weakening of trees.

Rootlet Mortality

Quantitative and proportionate estimates of rootlet mortality could not be made as some dead roots had deteriorated, and other dead and live roots could not be collected because they were too entangled with the roots of other plants including dead moss. Dead moss was especially

Table 9. Percent of trees with Hylobius warreni larval tunnels in black spruce damaged to various degrees by the spruce budworm in Newfoundland.

Cumulative total-defoliation category	Number trees sampled	Percent of trees with Hylobius
0-20%	58	21
21-40%	36	36
41-60%	37	43
61-80%	28	57
81-100%	33	39

important in preventing the collection of all tiny roots. Some roots were also lost because of the hardness of some soil layers, which caused roots to break. However, qualitative differences in root systems were large and were associated with damage. The undamaged trees had clusters of roots eminating at regular intervals throughout the root length (Fig. 4a). A few clusters were lost during excavation, but not enough to obscure the general impression of the overall quantity of rootlets present.

Trees with several years of defoliation and at least two years of recovery had decidely smaller number of rootlets than did the undamaged tree (Fig. 4b). This tree was judged to have 60% crown mortality. Again a few clusters of rootlets were lost during excavation, but not enough to obscure the difference between the rootlet system of damaged and undamaged trees.

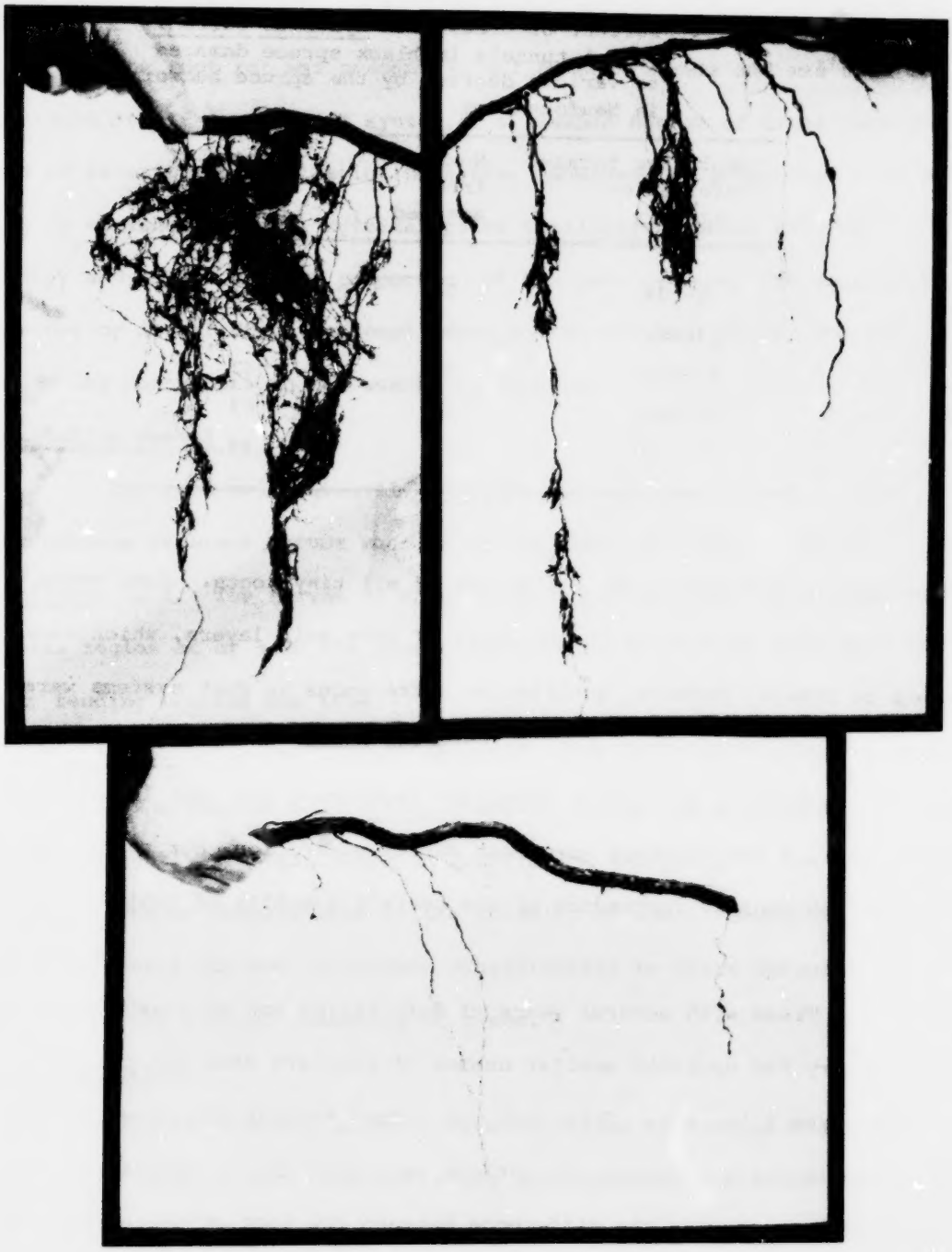

Figure 4. Section of black spruce root with rootlets in Newfoundland. (A) Undamaged tree. (B) Tree with 60% cumulative defoliation and recovering in 1983. (C) Tree with 40% cumulative defoliation and recent attack by the four-eyed spruce bark beetle, Polygraphus rufipennis.

The tree with 40% crown mortality, that had been recently attacked by bark beetles, had very few rootlet and even fewer rootlet clusters (Fig. 4c). All three roots sampled of this tree were similar in the quantity of rootlets present. One small root sampled had more rootlets present, though still a fewer than the tree in Figure 4b.

Small infections of Armillaria sp. were scattered in most living roots over 12 mm in diameter. All were apparently insignificant as judged by the cambial area covered, being only up to about 10 mm^2, and by the sharp demarkation line between infested and living tissues. Cambial areas in which Armillaria fans may be advancing rapidly is not sharply divided from living tissue but preceeded by a few millimetres of discolored cambium.

We concluded that past spruce budworm defoliation caused a sizable reduction in quantity of small roots and rootlets in black spruce. Also, two to three years of recovery growth is insufficient to re-grow a normal, complete root system. However, a reduced root system may be nearly sufficient to supply the requirements of a foliage complement reduced by several years of budworm defoliation. We surmise that root recovery growth must be sufficient to meet water requirements of recovery growth. If rootlet growth should lack water stress may result, causing the tree to succumb to secondary organisms.

Sample size was too small for exact definition of the relationship between rootlet mortality, and recovery from defoliation pressure. However this important relationship should be further investigated.

Miscellaneous

Bark samples checked for nematodes yielded no species likely to affect the health of the trees, including no nematode resembling the pinewood nematodes, Bursaphelencus xylophilus (Steiner and Buhrer).

In addition circumstantial evidence indicates that it is unlikely that acid rain was a factor in the decline in vigor and mortality of Newfoundland black spruce.

FORECAST

Spruce decline and mortality mushroomed in 1982 and continued slightly abated in 1983. However, the trend slowed in 1984 and even more so in 1985. It seems that almost all spruce that survived to 1985 are also likely to continue to survive. As trees continue to recover, it is likely that regrowth of rootlets will lessen water stress and regrowth of foliage will replenish depleted food reserves. Both trends should enhance survival by increasing resistance to attack by bark beetles and root fungi.

SUMMARY AND CONCLUSIONS

Black spruce was defoliated for three to four consecutive years in both central and eastern Newfoundland, causing an average cumulative total-defoliation of up to 44% of extensive areas of spruce.

Tree mortality increased to an estimated 3 200 000 m^3 by 1983 in stands on 95 700 ha of productive forest land. The stand volume containing this dead volume was estimated at 10 322 000 m^3.

Topkill was very common and nearly 100% of the defoliated trees had dead tops and 27% had dead tops greater than .2 m.

Symptoms of decline and sudden tree mortality were reddening and dropping of inner foliage in the fall, followed by increasing crown mortality and then death.

The bark beetle P. rufipennis and the root rot fungus Armillaria sp. (mellea complex) both enhanced the rate of tree mortality and probably also its extent.

Rootlet motrality had occurred during the years of defoliation but rootlet recovery had lagged behind that of foliage recovery in trees sampled.

The balance between crown recovery and rootlet recovery, plus unknown internal factors combined with the bark beetle and root rot fungus to effect the decline and sudden mortality of a large number of severely defoliated black spruce. Both decline and mortality abated in 1984 and more so in 1985. Trees that were alive in 1985 are likely to continue to survive and recover completely.

LITERATURE CITED

Hilton, D.F.J. 1968. A review of the genus Polygraphus. Univ. Kansas Sci. Bull. 48(2):21-44.

Hudak, J. and A.G. Raske (ed.). 1981. Review of the spruce budworm outbreak in Newfoundland - its control and forest management implications. Environ. Can., For. Serv., Newfoundland For. Res. Centre, Inf. Rep. N-X-205, 280 pp.

Moody, B.H. 1979. Spruce budworm damage assessment in Newfoundland in 1977 and 1978. Environ. Can., For. Serv., Newfoundland For. Res. Centre, Inf. Rep. N-X-173, 24 pp.

Moody, B.H. 1980. The status of the spruce budworm in Newfoundland in 1979. Environ. Can., For. Serv., Newfoundland For. Res. Centre, Inf. Rep. N-X-190, 41 pp.

Moody, B.H. and I.S. Otvos. 1979. The status of the spruce budworm in Newfoundland in 1978. Environ. Can., For. Serv., Newfoundland For. Res. Centre, Inf. Rep. N-X-171, 35 pp.

Otvos, I.S. and B.H. Moody. 1978. The spruce budworm in Newfoundland: history, status and control. Environ. Can., For Serv., Newfoundland For. Res. Centre, Inf. Rep. N-X-150, 76 pp.

Page, G., W.C. Wilton and T. Thomas. 1974. Forestry in Newfoundland. Environ. Can., For. Serv., Newfoundland For. Res. Centre, St. John's, Nfld.

Raske, A.G. and L.J. Clarke. 1982. The status of the spruce budworm in Newfoundland in 1980. Environ. Can., For. Serv., Newfoundland For. Res. Centre, Inf. Rep. N-X-208, 40 pp.

Raske, A.G., L.J. Clarke and W.J. Sutton. 1982. The status of the spruce budworm in Newfoundland in 1982. Environ. Can., For. Serv., Newfoundland For. Res. Centre, Inf. Rep. N-X-210, 49 pp.

Raske, A.G., L.J. Clarke and W.J. Sutton. 1986. The status of the spruce budworm in Newfoundland in 1982. Can. For. Serv., Newfoundland For. Centre, Inf. Rep. N-X-234. 51 pp.

Ross, D.A., G.A. van Sickle, R.L. Fiddick and D.G. Collis. 1978. Status of western spruce budworm in Douglas-fir in British Columbia. Environ. Can., For. Serv., Pacific For. Res. Centre, 4 pp.

Sutton, W.J. 1981. Data recording manual for defoliator damage assessment for conifers in Newfoundland. Environ. Can., For. Serv., Newfoundland For. Res. Centre, Inf. Rep. N-X-197, 23 pp.